Study of Kuroshio Intrusion and Transport using Moorings, HPIES and EM-APEX Floats

Ren-Chieh Lien
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, Washington 98105
Phone: (206) 685-1079 fax: (206) 543-6785 email: lien@apl.washington.edu

Thomas B. Sanford
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, Washington 98105
Phone: (206) 543-1365 fax: (206) 543-6785 email: sanford@apl.washington.edu

Award Number: N00014-08-1-0558

LONG-TERM GOALS

Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes—i.e., internal tides, inertial waves, NLIWs, and turbulence mixing—in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty. For this study, our focus is on small-scale processes (NLIWs and inertial waves), internal tides, and cold water intrusions generated as the Kuroshio and barotropic tides interact with the continental shelf of the East China Sea (ECS) and with one prominent submarine ridge (I-Lan Ridge) (Fig. 1). These small scale processes modulate the temporal, horizontal and vertical spatial structures of water properties in the ocean, and therefore may significantly modify oceanic acoustic properties and introduce uncertainty to sonar performance and acoustic propagation. Our ultimate goal is to collaborate with acousticians to identify oceanic processes that alter acoustic properties. Detailed properties, mechanisms, and dynamics of these oceanic processes will help quantify and assess the uncertainty in the acoustic prediction.

OBJECTIVES

The primary objectives of this observational program are 1) to quantify and to understand the dynamics of the Kuroshio intrusion and its migration into the southern East China Sea (SECS), 2) to identify the generation mechanisms of the Cold Dome often found on the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs on the SECS , and 5) to provide our results to acoustic investigators to assess the uncertainty in the acoustic prediction.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2008	**Annual**	**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE
Study Of Kuroshio Intrusion And Transport Using Moorings, HPIES and EM-APEX Floats

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Washington,Applied Physics Laboratory,1013 NE 40th Street,Seattle,WA,98105

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes??i.e., internal tides, inertial waves, NLIWs, and turbulence mixing??in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**8**	

APPROACH

A field observational program, as a part of an integrated observational program, is proposed (Figs. 1 and 2). Two components of the observational program are planned. For the 3-month extended observational program we will deploy an array of six 75-kHz Long Rangers with temperature/conductivity sensors, two in the Mien-Hua Canyon and four on the continental slope between the North Mien-Hua Canyon and Mien-Hua Canyon. These observations will be used to quantify the Kuroshio intrusion and migration, internal tidal energy and energy flux, NLIWs, and the Cold Dome. For the ~1/2-month intensive observational program on the continental shelf, overlapping with the extended observational program, we will deploy four EM-APEX floats in the Mien-Hua Canyon and two in the Cold Dome. These EM-APEX floats will provide near real-time observations.

WORK COMPLETED

- In the past year, we attended three ONR workshops, discussed and helped define the integrated observational program.

- In July 2007 a Long Ranger ADCP bottom-mounted mooring was deployed on the slope of Mien-Hua Canyon (red bullet in Fig. 2). The mooring was to be recovered in November 2007. During the November recovery, the sea state was bad and the mooring recovery operation was aborted. We returned to recover in December 2008. Unfortunately, we were not able to locate the mooring. We sent signals from acoustic release transmitter to the acoustic releases but received no response from the pair of acoustic releases on the mooring. We surveyed the experiment site for 12 hrs and repeated acoustic transmission to locate our mooring, but found no trace of the mooring.

- We performed preliminary analysis of historical CTD data and mooring observations to quantify effects of oceanic processes on the sound speed (Figs. 3–7).

- We submitted a DURIP proposal in 2007 to acquire EM-APEX floats. The proposal was funded and we are purchasing EM-APEX floats.

- We submitted a DURIP proposal in August 2008 to acquire ADCP-CTD chains.

- We continue working with Taiwanese collaborators to understand the internal tide generation at the SECS. Dr. Jan runs the POM model at 1’ longitude x 1’ latitude resolution, which is sufficient to resolve canyons in the East China Sea.

RESULTS

In July 2007 we deployed a bottom-mounted Long Ranger ADCP on the slope of the Mien-Hua Canyon at 600-m depth (Fig. 2). The location was chosen where numerical models suggest strong internal tides (Jan, personal communication) and possible Kuroshio intrusion (Lermusiaux, personal communication). Unfortunately, this ADCP mooring was lost.

Historical CTD data collected by the National Center for Ocean Research (NCOR) between 1985 and 2002 were used to compute the fluctuations of sound speed in different regions along the Kuroshio path and across the continental shelf and slope (Fig. 3).

Standard deviations of sound speeds averaged in the areas north and south of I-Lan ridge are shown in Fig. 4. A band of large standard deviation, extending from the surface to ~200 m in the north of I-Lan ridge, might represent the effect of the migration of the Kuroshio front. A deeper band near 400-m depth may be associated with the base of the Kuroshio. The strong sound speed anomaly is also found in the upper ocean, likely associated with the change of the thermal structure in the surface mixed layer.

The Kuroshio interaction with the continental slope and shelf could lead to large fluctuations of sound speed (Fig. 5). A ~100-km horizontal band of strong sound speed anomaly was found emanating from the continental shelf break of SECS. Small patches of large sound speed anomaly on the continental shelf may be associated with NLIWs.

Above Mien-Hua Canyon and North Mien-Hua Canyon, the largest sound speed anomaly was found with the maximum standard deviation about 10 m s^{-1} (Fig. 6). We attribute this anomaly to NLIWs often observed by satellite.

The sound speed anomaly induced by oceanic processes in the SECS is summarized in Fig. 7. The Kuroshio interaction with the continental shelf and slope introduce the sound speed anomaly, i.e., standard deviation of about 5 m s^{-1}, which decays with depth. Such a sound speed anomaly has a horizontal scale of O(10s–100 km). NLIWs on the continental shelf may introduce a sound speed anomaly as large as 10 m s^{-1} with the horizontal scale O (1km) in a short time scale O(10s min). In comparison, NLIWs observed in the Philippine Sea generate a much weaker sound speed anomaly. Internal tides also cause sound speed anomalies as large as 5 m s^{-1} centering at the thermocline.

Numerical model results of semidiurnal internal tides, performed by Dr. Jan, at 1’ longitude x 1’ latitude resolution are shown in Fig. 8. Strong internal tidal energy fluxes are found at the shelf break south of Mien-Hua Canyon between the 200-m and 500-m isobaths. There is also significant internal tidal energy at the canyon head propagating down the canyon. The down-canyon internal tidal energy flux is ~10 kW m^{-1}. Further analysis of numerical model results is in progress. Our observations from ADCP-CTD moorings and from EM-APEX floats will be compared with numerical model results.

IMPACT/APPLICATION

Our preliminary analysis concludes that strong sound speed anomalies are induced by NLIWs, internal tides, and processes associated with the Kuroshio interaction with the continental slope and shelf. Such sound speed anomalies have the temporal and spatial scales and characteristics associated with the corresponding oceanic processes. To quantify, predict, and exploit the uncertainty of acoustic propagation and sonar performance, we need to understand the dynamics of these oceanic processes and their effects on the sound speed. This is the main goal of the proposed experiment.

RELATED PROJECTS

Energy Budget of Nonlinear Internal Waves near Dongsha (N00014-05-1-0284) as a part of NLIWI DRI: In this project, we study the dynamics and quantify the energy budget of nonlinear internal waves

(NLIWs) in the South China Sea using observations taken from two intensive shipboard experiments in 2005 and 2007 and a set of nearly one year of velocity-profile measurements taken in 2006-2007 from three bottom mounted ADCPs across the continental slope east of Dongsha Plateau in the South China Sea. Results of NLIWI DRI will help improve our understanding of the dynamics of NLIWs and apply to the present project.

Process Study of Oceanic Responses to Typhoons using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of ITWP DRI: We will study the dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific using long-term mooring observations and an array of EM-APEX floats. Pacific typhoons may cause cold pools on the continental shelf of the East China Sea. The cold pool dynamics are likely related to the Kuroshio and its intrusion as well as the shelf/slope oceanic processes. The cold pool could produce a significant acoustic anomaly that is the focus of the present project.

HONORS/AWARDS/PRIZES

Gledden Sr. Visiting Fellowship at U. Western Australia (Sanford)
SecNav/CNO Chair in Oceanographic Sciences (Sanford)
IEEE/OES Distinguished Technical Achievement Award (Sanford)

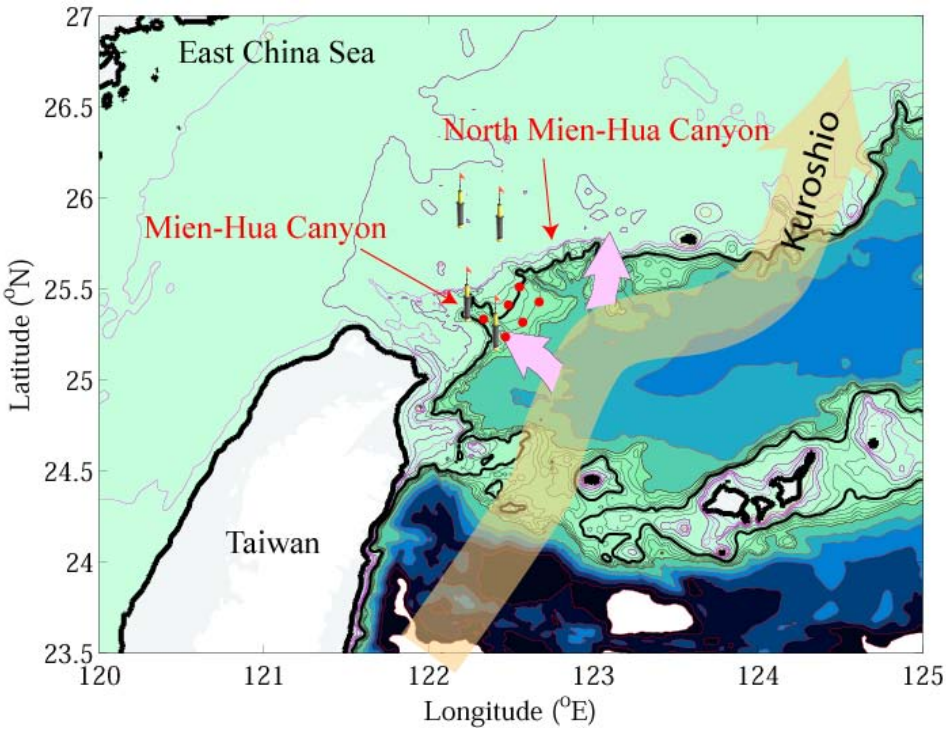

Figure 1: Bathymetry map of the southern East China Sea. The contour interval is 100 m between 0 and 1000-m depth and is 500 m for depth greater than 1000 m. Thick solid curves indicate 0 and 500-m isobaths. The Kuroshio main path and intrusion paths are illustrated. Six dots mark the tentative location of the ADCP moorings. Four EM-APEX floats are illustrated.

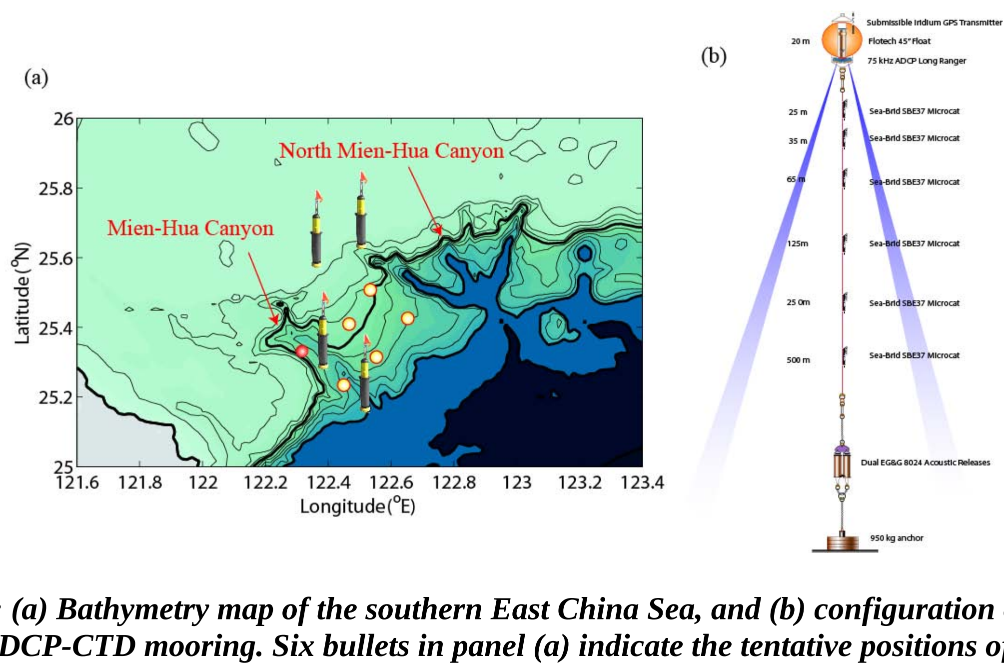

Figure 2: (a) Bathymetry map of the southern East China Sea, and (b) configuration of bottom mounted ADCP-CTD mooring. Six bullets in panel (a) indicate the tentative positions of the ADCP moorings. The red bullet indicates the position of ADCP deployed in July 2007. Four EM-APEX floats are illustrated.

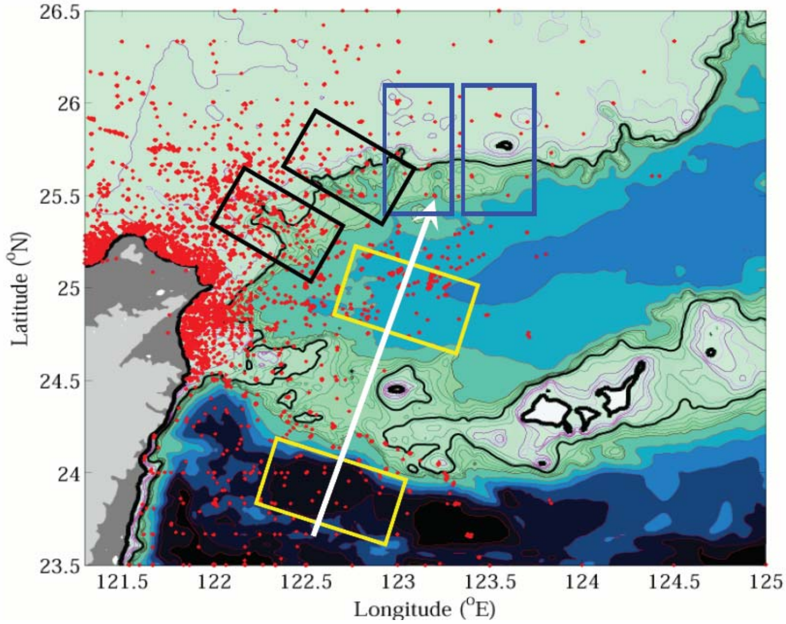

Figure 3: Locations of historical CTD data (red dots) and area sections where CTD data are used to compute the sound speed anomaly.

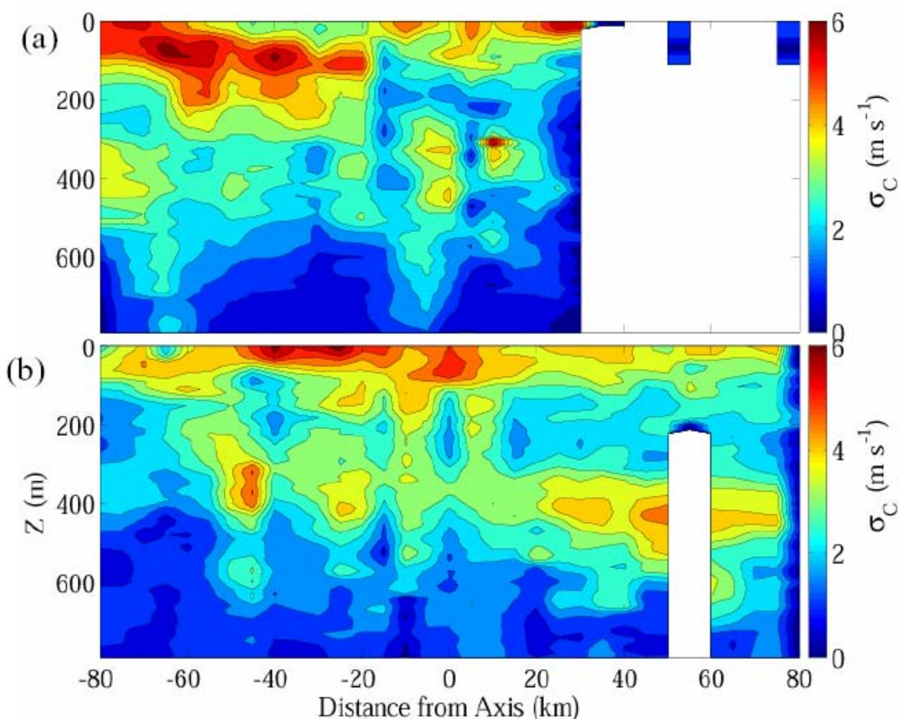

Figure 4: Standard deviations of sound speed averaged over sections at (a) north of I-Lan Ridge (the top yellow box in Figure 3), and (b) south of I-Lan Ridge (the bottom yellow box in Figure 3).

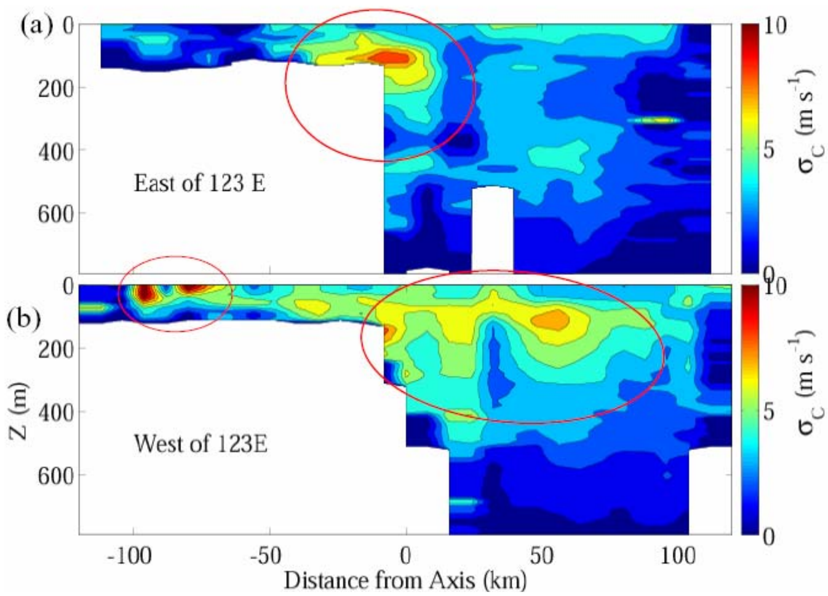

Figure 5: Standard deviations of sound speed averaged over sections across the continental slope and the continental shelf on the main path of the Kuroshio at (a) east of 123 ^{o}E (the right blue box in Figure 3) and (b) west of 123 ^{o}E (the left blue box in Figure 3).

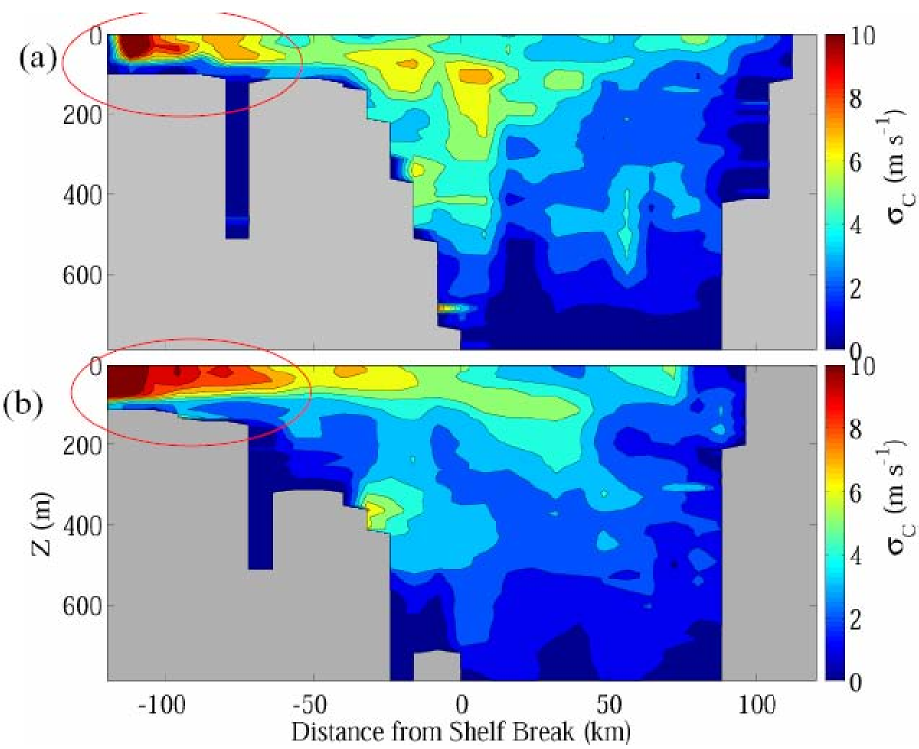

Figure 6: Standard deviations of sound speeds averaged over sections across the continental slope and the continental shelf on possible intrusion paths of the Kuroshio centering around (a) North Mien-Hua Canyon (the top black box in Figure 3) and (b) Mien-Huan Canyon (the bottom black box in Figure 3).

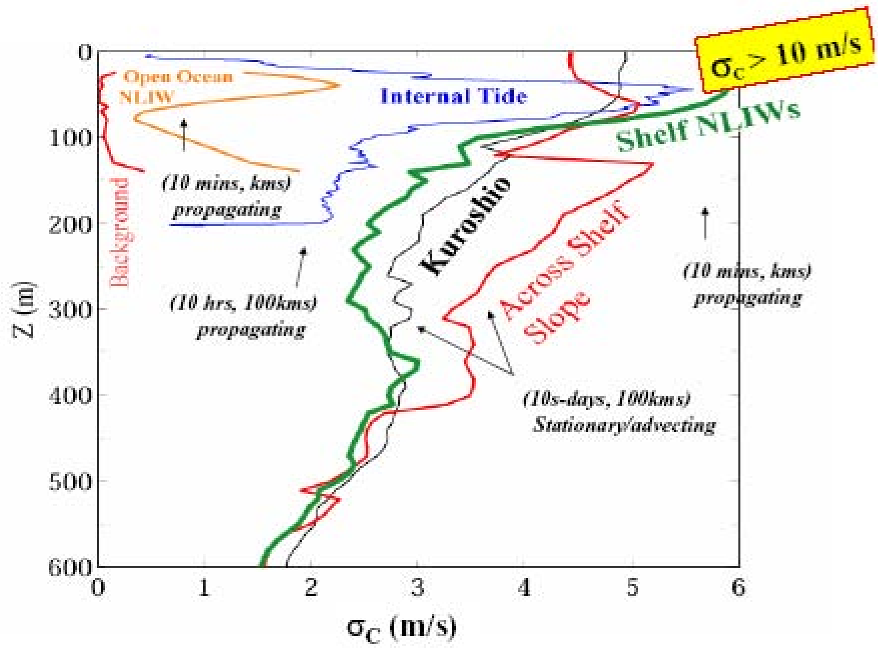

Figure 7: Summary of the sound speed anomaly introduced by primary oceanic processes along the Kuroshio path near the southern East China Sea. Typical temporal and spatial scales and characteristics of oceanic processes are labeled. The standard deviation of sound speed associated with NLIWs on the continental slope exceeding 10 m s^{-1} is highlighted.

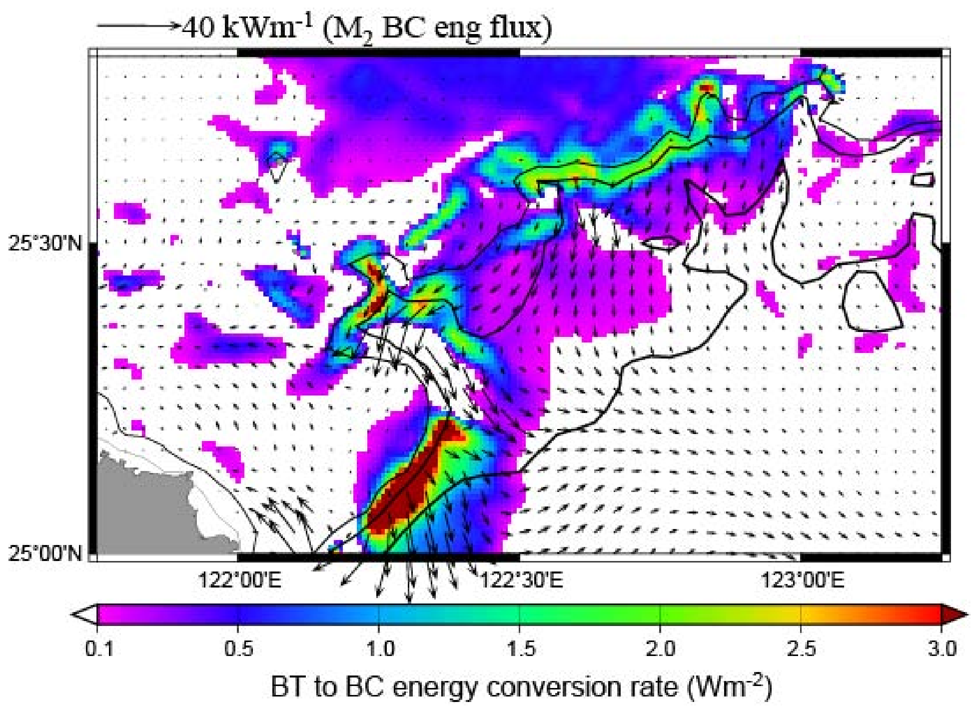

Figure 8: Numerical model results of M2 internal tidal energy flux (vectors) and the M2 barotropic to baroclinic tidal energy conversion rate (color contours). Black contour lines represent isobaths of 200 m, 500 m, and 1000 m.